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Effects of Self-Assisted Shoulder Elevation of the Affected Side Combined with Balance Training on Associated Reactions of Upper Limb and Walking Function in Chronic Stroke Patients: A Randomized Controlled Trial

Authors' Contribution:

Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

BC 1 Wenjun Jiang
AG 2 Sheng Wang
DF 2 Qinfeng Wu
E 2 Xiangzhe Li

1 Department of Rehabilitation Medicine, Suzhou Vocational Health College, Suzhou, Jiangsu, P.R. China

2 Department of Rehabilitation Medicine, The Affiliated Suzhou Science and Technology Town Hospital of Nanjing Medical University, Suzhou, Jiangsu, P.R. China

Corresponding Author: Sheng Wang, e-mail: wangshengkf@163.com

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Background: Associated reactions of the upper limb are frequently seen in stroke patients, especially during dynamic activities, such as walking. The aim of this study was to assess the effect of a method to inhibit the affected upper limb flexors combined with balance training on associated reactions of the affected upper limb and walking function in chronic stroke patients.


Material/Methods: 60 patients were randomly allocated into 3 groups (n=20 per group): control group (no upper limb intervention), back group (the unaffected hand assists the affected upper limb in the low back and keep it in an extended position) and shoulder elevation group using the inhibition method (the unaffected hand assists the affected shoulder to elevate above 90°). Before and after the four-week balance training, the surface electromyography was used to evaluate the rate of contraction of affected elbow flexors. Fugl-Meyer Assessment of Upper Extremity (FMA-UE), 10 Meter Walking Test (10MWT) and Barthel Index (BI) were used to measure functional status.

Results: The shoulder elevation group had significant improvement in the percentage changes in the rate of contraction of the affected elbow flexors, 10MWT and FMA-UE ($p < 0.05$) compared with back group and control group. We found no significant difference of 10MWT and FMA-UE between back group and control group.

Conclusions: The combination of the new inhibition method and the standing balance training could reduce the abnormal activity of affected elbow flexors during walking, increase walking speed, and improve the affected upper limb motor function.

Keywords: **Electromyography • Muscle Spasticity • Postural Balance • Stroke • Upper Extremity**

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Background

Upper-extremity dysfunction is a common complication in stroke patients, and only 5-20% of patients have complete functional recovery within 6 months after stroke [1,2]. Patients with cerebral injury usually present abnormal motor patterns, such as upper-limb-associated reactions (AR) [3,4], which can affect dynamic upper-limb function [5,6] and activities of daily living [7].

At present, only a few studies have investigated the mechanism and treatment of AR, and even the terminology of this pathological phenomenon is not consistent [8]. AR often occurs while the other parts of the body overly exert strength [9,10]. Previous studies mostly focused on the influence of the unaffected hand grasp or elbow flexion accompanying resistance on the AR of the affected upper limb in static sitting position [11]. However, static sitting position may not measure the actual degree of AR because AR is most likely to be induced during dynamic conditions. In recent years, some researchers have used structural measurement scales [12] and three-dimensional motion analysis systems [13] to observe characteristics of upper-limb AR during walking. Currently, the treatment for upper-limb AR is mainly focused on physical and pharmacological aspects [14]. Botulinum toxin injection can block the excitability of targeted muscle and reduce the generation of AR [15], but this method only has a short-term effect [7] and is expensive. Although some studies have pointed out that muscle spasticity and AR usually occur at the same time [16,17], some have suggested that there is no relationship between spasticity and AR [18,19]. The method of locally inhibiting the excitability of targeted muscle through botulinum toxin injection seems to be unable to effectively reduce upper-limb AR in the long term.

Previous studies have suggested that the increase of involuntary flexor spasticity together with a flexed-abducted posture of the affected upper limb during walking could be related to postural instability in stroke [20] and cerebral palsy patients [21]. This altered arm posture may be mainly related to walking instability in the anterior-posterior direction [22]. It has been found that the spasticity of hemiplegic elbow flexors in the standing position is significantly higher than that in the supine or the sitting position, suggesting that differences in postural balance affect hemiplegic upper-limb spasticity [23]. Our previous study showed that the spasticity of the affected elbow flexor increased with the gradually increased challenge in standing balance [24], indicating that posture balance disorder after stroke can lead to spasticity aggravation of the hemiplegic upper-limb flexor. The emergence of AR in the hemiplegic upper limb during walking can be described as an increased spasticity of the hemiplegic upper limb. This muscle response can be described as a kind of compensation strategy

to maintain balance during walking. If investigators inhibited the abnormal activity of the affected upper-limb flexor and increased balance challenge for patients, the patients would need to maintain balance with no or a reduced amount of participation of the affected upper limb and increase muscle activities of the trunk and the lower extremities for balance training.

In clinical rehabilitation practice, there are several ways for physical therapists to inhibit patients' abnormal activity of hemiplegic upper-limb flexor during dynamic activities such as walking. One common way is to use the unaffected hand to assist the affected upper limb to extend to behind the back. We designed a novel self-restriction method, instructing the patients to use their unaffected hands to elevate the affected shoulder to above 90°. They needed to maintain the elbow at an extended position, which might decrease the flexor activity and reduce depression of the shoulder girdle and upper trunk. We used the 2 inhibition methods in this study to reduce abnormal activity of the upper-limb flexor on the hemiplegic side, and we carried out balance training. We aimed to observe: 1) changes in muscle activity of hemiplegic upper-limb elbow flexors during walking; and 2) potential effects on upper-limb function and walking speed. The outcomes of this study might inspire the development of novel intervention strategies for the treatment of upper-limb spasticity and AR.

Material and Methods

Participants

Hemiplegic chronic stroke patients were recruited from the Affiliated Suzhou Science and Technology Town Hospital of Nanjing Medical University. We randomly allocated 60 patients into a control group, a back group, and a shoulder elevation group. Inclusion criteria were: (1) first subcortical cerebral hemorrhage or cerebral infarction; (2) age 20-70 years old; (3) disease course more than 6 months; (4) able to walk indoor independently without assistive devices, and presented with AR of the hemiplegic upper limb during walking; (5) Modified Ashworth Scale of elbow flexor in sitting position \leq grade 3; (6) normal cognitive function, MMSE \geq 24; and (7) agree to participate the treatment procedure and sign the informed consent. Exclusion criteria were: (1) walking with crutches or other walking aids; (2) cognitive impairment or hearing and understanding impairment, unable to accept simple motor instructions; (3) other neurological and musculoskeletal related diseases such as encephalitis, Parkinson's disease, multiple sclerosis, and peripheral neuropathy; (4) serious heart, lung, liver, and kidney function insufficiency, malignant tumor, serious infection, new trauma or fracture, and malignant progressive hypertension. The sample size was estimated according to the method described in a similar study [25], with 60 patients in

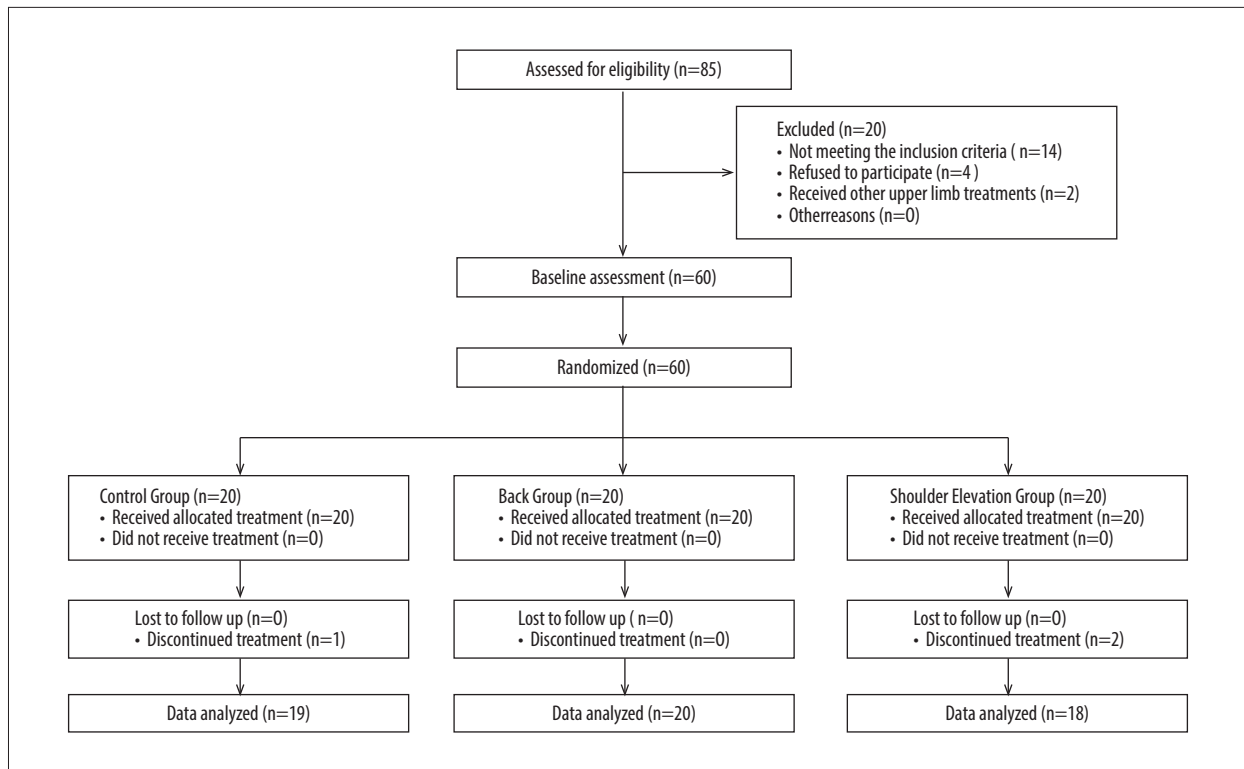


Figure 1. Flow diagram of the participants selection.

total, and 20 in each group. The flowchart of patient recruitment is described in **Figure 1**.

Study Design

This study was a randomized controlled clinical trial for post-stroke patients, with blinding of both patients and assessors. Allocation sequence numbers via random number tables were generated by physician 1, who was not included in the study team. The outcome measures before and after the treatment were assessed by physician 2, who was blinded to the group assignment. The treatments were carried out by a physical therapist who was blinded to the outcome measurements.

This study was reviewed and approved by the Ethics Committee of Suzhou Municipal Hospital (No. IEC-C-008-A07-V1.0) and registered with the Chinese Clinical Trial Registry (ChiCTR1800014827) (<http://www.chictr.org.cn/showproj.aspx?proj=25287>). The research protocol was conducted according to the Declaration of Helsinki.

Interventions

All patients in these 3 groups underwent a routine, comprehensive rehabilitation program with occupational therapy and physical therapy to improve motor function of the affected extremities and walking function. Before the experiment, all

physiotherapists in the stroke rehabilitation group compared the instant effect on flexor activity of the following methods based on their own experience: 1) maintaining the elbow joint in an extended position by using a fixed brace; 2) maintaining the affected hand at the low back with the assistance of the unaffected hand; 3) maintaining the affected shoulder in an elevated position with the assistance of the unaffected hand; and 4) no intervention to the affected upper limb. They concluded that the fixed brace could increase the electromyogram (EMG) amplitude of the biceps brachii, while the other 2 methods could keep the elbow joint in an extended position without increasing the EMG signal of the biceps brachii.

The 3 groups maintained 3 different upper-limb conditions while undergoing progressive balance training. In the control group, the patients were instructed to place their arms naturally by the 2 sides of the trunk without any intervention (**Figure 2A**). In the back group, the patients were instructed to put their affected hand at their low backs. They were asked to maintain the elbow joint in an extended position with the assistance of the unaffected hand (**Figure 2B**). This position has been commonly used in physical therapy practice to inhibit flexor spasticity during walking. In the shoulder elevation group, the affected shoulder was elevated to over 90° with the assistance of the unaffected arm (**Figure 2C**). The principle of designing this new inhibition method was that the self-assisted shoulder flexion can extend the elbow joint and elevate the

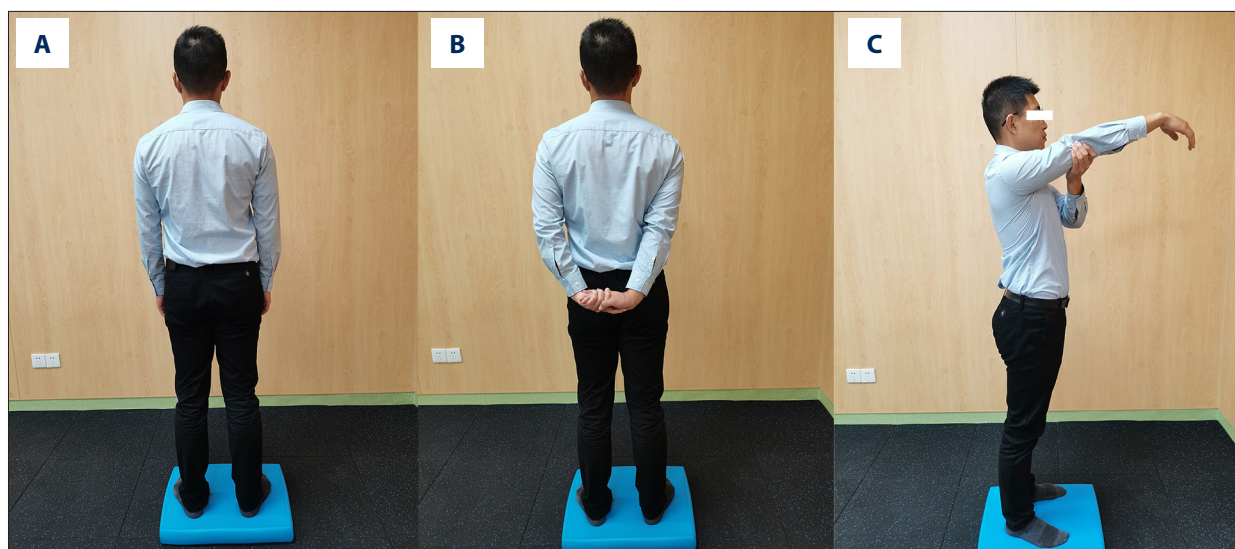


Figure 2. Upper-limb conditions in 3 groups: (A) Control group, (B) Back group, (C) Shoulder elevation group. The affected upper limb is on the right side.

shoulder joint at the same time, which can correct the depression and retraction of the scapula as well as lateral inclination of the affected side of the trunk, keeping the axial structures aligned in the vertical direction.

Gradually increasing the postural balance challenge was conducted through varying the sizes and materials of the base of support (BoS). We varied the size of the BoS by asking the participants to place their feet apart and place their feet together. All participants were tested with their feet put together first. We varied the materials of BoS by asking the participants to stand on a hard floor and a soft pad (Joifit, length×width×height=49×39×5 cm, respectively). All participants started their test on the hard floor first.

Each group underwent the same balance training program, with 30 minutes per training session, one session per day, 5 days a week for 4 weeks. All treatment was carried out under the supervision of the therapist or with their support. If the participant could not maintain the posture balance and needed continuous external support, the balance training difficulty was reduced. In addition, the affected upper limb should be elevated to over 90° degrees of shoulder flexion, and participants who failed to maintain this upper-limb position during training could rest for several seconds.

Assessment

EMG Test

Wireless surface electromyography (Noraxon, Inc., Scottsdale, AZ, USA) recorded the 10-second electromyographic activities of bilateral biceps brachii and triceps brachii muscles during

walking at a self-selected speed. Skin preparation was performed according to the criterion of ‘The ABC of EMG’ before the test. Two EMG electrodes (Noraxon, USA) were used. One was attached to the lower one-third of the line between the acromion and the elbow fossa (biceps brachii), and one was attached to the midpoint between the acromion and the olecranon of ulna (triceps brachii). We used a wireless accelerometer (myoMOTION, Noraxon, USA) to mark the ‘time zero’ (T0), which was the time point when the subject started walking (Figures 3, 4).

EMG Processing

The data were analyzed using MyoResearch software (MyoResearch 3.10, Noraxon, USA). EMG signals were full-wave rectified and filtered with a 100-Hz low-pass, 2nd-order, zero-lag Butterworth filter [26]. T0 was defined as the first time frame when the acceleration magnitude reached 5% of the maximum value. Mean integrals of the EMG activities were calculated for a 10-second duration after T0.

In previous studies, EMG signals were normalized with Maximum Voluntary Contraction (MVC) to allow comparisons between tasks and participants. Considering the flexion synergy pattern of post-stroke patients, flexors are co-activated during the motor task. When testing the MVC of a certain muscle, the participant would need produce flexion and extension movement on the single joint in this trial. Most of our patients cannot produce the required movement, so we used the non-normalized integral EMG. In this study, the contraction rate of elbow flexors was used to express the synergic/antagonistic contraction of elbow flexors and extensors, which might be a good index to reflect the changes of muscle tone in postural control [24]. The details are provided in a previous study [24].

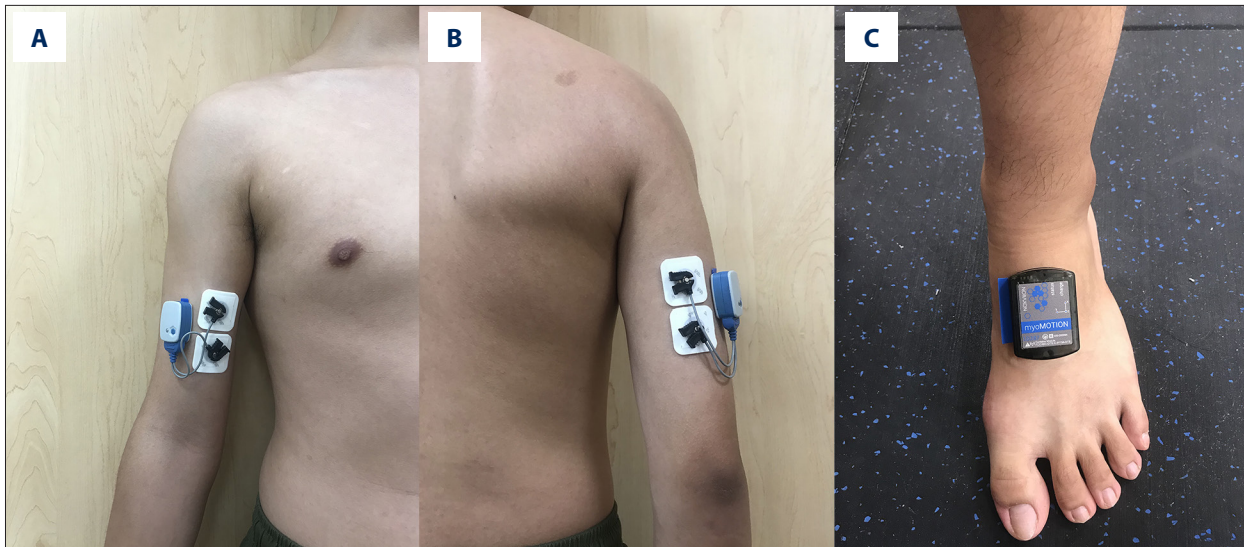


Figure 3. Placement of EMG sensors (A, B: in the arm) and accelerometers (C: in the dorsal of foot).



Figure 4. (A, B) Experimental setup.

The formula was as below:

$$\frac{\text{Mean } iEMG \text{ biceps brachii}}{\text{Mean } iEMG \text{ triceps brachii}} = \text{contraction rate of elbow flexor}$$

Clinical Measurements

The clinical scale we used included the Fugl-Meyer Assessment of Upper Extremity (FMA-UE), the 10 Meter Walking Test (10MWT), and the Barthel Index (BI).

FMA-UE consists of 10 items and 33 sub-items, with good reliability and validity [27]. The highest score of each sub-item is 2, with a total score of 66. The content of this scale contains the synergic movement of the shoulder/elbow/wrist joints, the stability of the wrist joint, as well as the coordination and speed of small-joint movement. All subjects are asked to walk for 10 meters at their fastest speed without assistance during the 10MWT, and the recorded time is accurate to 0.1 second. Each participant was tested 3 times, and the mean value of the 3 observations was calculated for data analysis [28].

Table 1. Demographic information of the 3 groups of participants measured during pre-treatment (data is presented as mean±standard deviation).

	Control group (n=19)	Back group (n=20)	Shoulder elevation group (n=18)	P-value
Sex (M/F)	10/9	11/9	10/8	0.98
Affected side (L/R)	9/10	10/10	9/9	0.98
Stroke type (CH/CI)	11/8	11/9	11/7	0.93
Age (yo)	55.94±6.81	55.27±7.85	58.39±6.31	0.39
Body weight (kg)	70.83±9.19	65.47±12.42	69.78±13.08	0.39
Body height (cm)	170.78±4.60	168.13±5.42	169.11±5.79	0.42
Course	8.94±1.30	9.27±1.62	8.67±1.53	0.52

CH – cerebral hemorrhage; CI – cerebral infarction; M – Male; F – Female; L – left; R – right.

Table 2. Comparison of clinical measurements and the rate of contraction of the affected elbow flexors between pre- and post-treatment (data shown as mean±standard deviation).

Variables	Control group		Back group		Shoulder elevation group	
	Pre	Post	Pre	Post	Pre	Post
FMA-UE	24.00±2.97	25.50±2.87*	24.60±2.53	26.27±3.81*	23.56±4.60	28.56±4.40*
BI	82.22±7.90	85.83±6.00*	81.67±9.76	86.67±6.17*	78.61±7.03	84.17±6.00*
10MWT	0.80±0.06	0.85±0.07*	0.81±0.07	0.88±0.07*	0.83±0.05	0.95±0.03*
Contraction rate of affected elbow flexors	2.33±0.73	2.58±0.95	2.30±0.53	1.78±0.37*	2.48±1.07	1.12±0.31*

* Significant difference within groups. Pre was performed before the treatment, and post was performed after 4 weeks treatment.

BI has a good reliability and contains 10 items with a total score of 100 [29].

Statistical Analysis

First of all, we conducted a series of Pearson's chi-squared test and one-way ANOVA to determine if there were any difference in sex, affected side, stroke type, age, body weight, and body height across the 3 groups of participants prior to the treatment. We also compared the clinical scores and the rate of contraction in the pre-treatment test using one-way analysis of variance (ANOVA) to detect any difference among the 3 groups. We tested the normality of our data using the Shapiro-Wilk test. If our data did not violate normal distribution, we first used the paired-sample *t* test to compare the rate of contraction of the elbow flexors and clinical scores (FMA-UE, 10MWT, and BI) between pre- and post-treatment. To evaluate the effect of different treatment types, we then used one-way ANOVA with 3 levels to compare the percentage of changes in the rate of

contraction of the elbow flexors and clinical scores across the 3 groups. If our data violated normal distribution, we would use the non-parametric equivalents of paired-sample *t* test and one-way ANOVA to test statistical differences. Post hoc pairwise comparisons with Bonferroni corrections were conducted when indicated. We used SPSS (Version 20.0, IBM, Chicago, IL, USA) for all statistical analyses. We set the global alpha level at 0.05.

Results

There were no significant differences in age, body weight, body height, and courses between the 3 groups (**Table 1**). During the pre-treatment test, there were no significant difference in clinical scores (FMA-UE: $p=0.18$; BI: $p=0.64$; MWT: $p=0.56$) or the rate of contraction of affected elbow flexors ($p=0.99$) among the 3 groups. **Table 2** shows the results of the shoulder elevation group, the back group, and the control group that were recorded pre- and post-treatment.

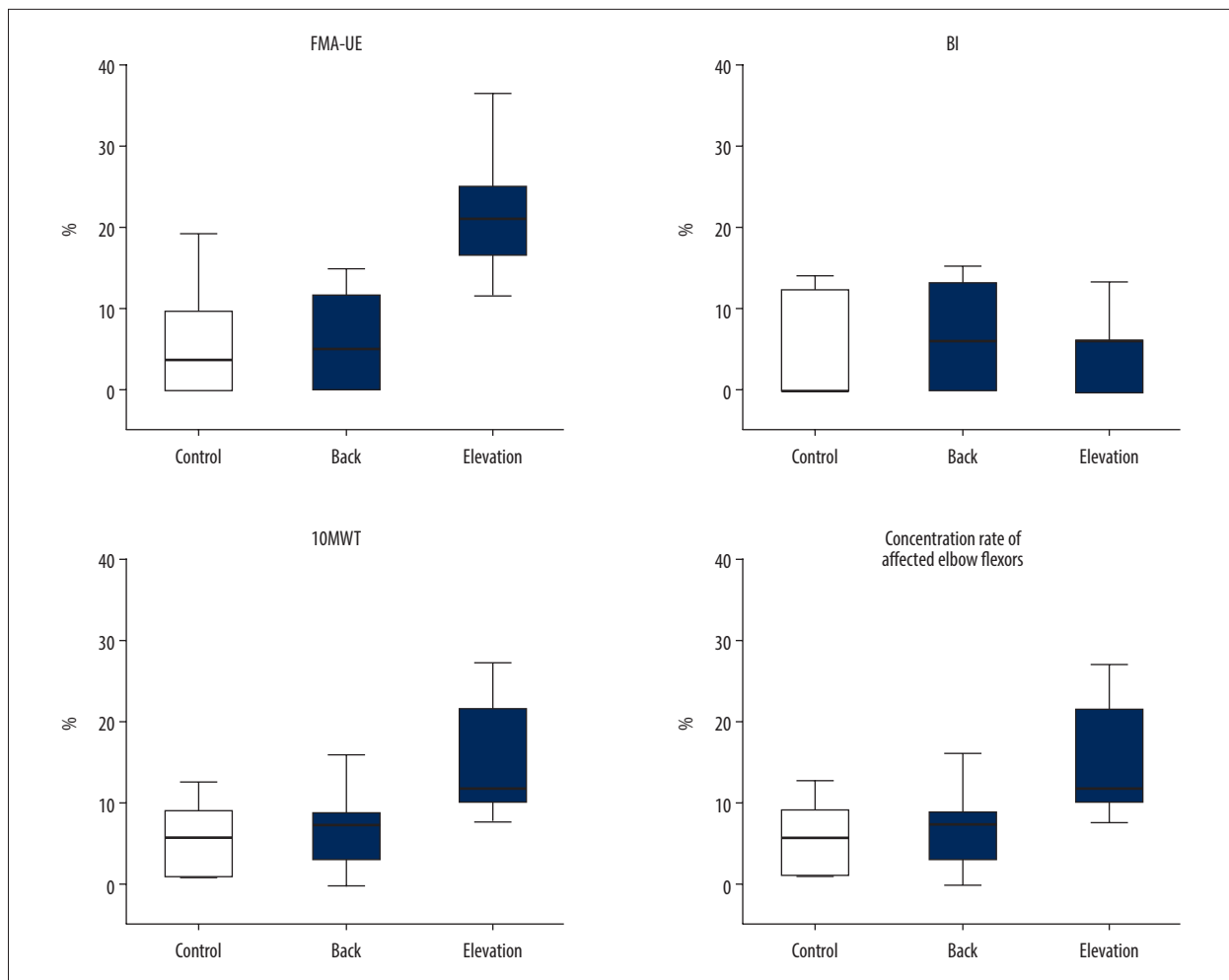


Figure 5. The percentage of changes in clinical scores and the rate of contraction in elbow flexors. The percentage of changes is calculated as post-treatment minus pre-treatment, and it was then divided by pre-treatment data and multiplied 100%.

Results of normality testing (Shapiro-Wilk) showed significant difference in the percentage of change in the rate of contraction of the affected elbow flexors ($P<0.001$), FMA-UE ($P<0.001$), 10MWT ($P=0.001$) and BI ($P=0.009$) after treatment. Since our data violated normal distribution, we used the Kruskal-Wallis test to assess the significance of differences.

The Kruskal-Wallis test showed that there were significant differences in the percentage of change in the rate of contraction of affected elbow flexors ($P<0.001$), FMA-UE ($P<0.001$), 10MWT ($P<0.001$) in the 3 groups, except for the BI ($P=0.73$). Post hoc pairwise comparisons with Bonferroni corrections revealed that the percentage change in the contraction rate of affected elbow flexors ($P=0.02$; $P<0.001$), 10MWT ($P<0.001$; $P<0.001$) and FMA-UE ($P<0.001$; $P<0.001$) showed a significantly greater improvement in the shoulder elevation group compared to the back group and control group, but there was no significant difference in 10MWT and FMA-UE between the back group and control group (Figure 5).

Discussion

This study investigated the effects of a combination of self-assisted shoulder elevation of the affected side and balance training on elbow flexor activities of the affected upper limb, upper-limb motor function, walking function, and activities of daily living in chronic stroke patients. We found that the shoulder elevation group showed significant improvement in the rate of contraction of affected elbow flexors, 10MWT performance, and upper-limb motor function. Our results indicated the advantage of the self-assisted shoulder elevation of the affected side combined with balance training.

Inhibiting the affected upper-limb flexors combined with balance training significantly reduced the rate of contraction of affected elbow flexors, and the elbow flexor spasticity on the affected side was relieved during walking. According to Meyns et al, the flexed posture of the upper limbs observed in cerebral palsy patients during walking can be caused by

postural instability [21], especially instability in the anterior-posterior direction [22]. Qin et al [23] assessed spasticity of the affected flexor muscle in the supine, sitting, and standing positions in hemiplegic stroke patients, and found that the spasticity was significantly higher in the standing position than in the supine or sitting positions. Our previous study showed that the rate of contraction of the affected elbow flexors increased with the increased balance challenge in different standing postures [24]. These findings suggested that posture balance plays an important role in the spasticity regulation of hemiplegic upper limbs, and the augmentation of affected elbow flexor activities while in upright positions may be a compensatory strategy to maintain balance. The findings of the present study suggest that affected elbow flexor activity participates less in maintaining balance when using the novel self-restriction method to elevate the affected shoulder joint to above 90° and to extend the affected elbow. The reduction of the affected elbow flexor activity during walking could be due to the isolated balance training with more involvement of muscles of the axial trunk and the lower limbs.

The outcomes of this study showed that after 4 weeks of balance training, there was a borderline significant increase in walking speeds in the shoulder elevation group, which suggests that the hemiplegic upper-limb flexor spasticity affects the walking speed. Previous studies showed an increase in the range of motion in the affected knee joint in stroke patients during walking after local injection of botulinum toxin [15,30]. Hirsch et al [31] reported that there was a correlation between the botulinum toxin treatment in the upper limb of hemiplegic stroke patients and the increase of stride length and range of motion of the affected knee and ankle joints. Esquenazi et al [32] found that walking speed increased from 0.56 m/s to 0.63 m/s and the upper-limb Modified Ashworth Scale scores decreased from 2.6 to 1.4 after 120-200 U botulinum toxin was injected into the biceps brachii and brachioradialis brachii. These findings suggest that reduction of the affected elbow flexor activities may be associated with improvement in walking ability. In the current study, the flexor inhibition method of a self-assisted shoulder elevation reduced the rate of contraction of hemiplegic elbow flexors and improved 10WMT performance. Our results are consistent with the previous findings of improving walking ability through botulinum toxin injection to inhibit elbow flexors. The possible reason for the improvement in walking speed in the shoulder elevation group could be that the self-assisted shoulder elevation promoted the isolated movement of scapula, trunk, and lower limbs in the affected side, thus contributing to the weight-bearing support and center of gravity transfer on the affected leg.

This study showed a borderline significant increase in the affected upper-limb motor function in the shoulder elevation group compared with the back group and control group, which suggests that the decrease of hemiplegic upper-limb flexor spasticity during standing balance maintenance aids recovery of affected upper-limb motor function. Several investigations of hemiplegic scapular stability training in the standing position [33] found that after 8 weeks of treatment, both walking ability and hemiplegic hand function improved. This indicates that scapula stability might play a vital role in improving the function of lower and upper limbs. The weakness of the scapular stabilizing muscle could decrease motor function of the upper limb and affect ability to independently perform activities of daily living [34]. Spasticity of flexor muscles in the affected upper limb during dynamic activities usually was accompanied by the depression and retraction of the scapula, flexion of the elbow joint, pronation/supination of the forearm, and flexion of the wrist. In this study, this inhibition method of self-assisted shoulder elevation may help in extension of the elbow joint, the upward rotation of the scapula, and the separation of the scapula and the trunk. This method could further adjust the relationship between the trunk and the scapular, which would have a positive effect on upper-limb function.

Most patients reported fatigue in the unaffected upper limb during self-assisted shoulder elevation, which might increase the difficulty for patients to participate in balance training. This phenomenon may be due to the increased spasticity of scapular depression and retraction. Follow-up research needs to design a mechanical brace to assist shoulder elevation and further analyze the kinematic parameters of the affected upper limb.

Conclusions

The current study investigated the effect of a new inhibition method combined with balance training on the dynamic spasticity of upper-limb and walking function. The results showed that the new method could reduce the rate of contraction of the affected elbow flexors during walking, increase the walking speed, and improve upper-limb motor function. To further verify its clinical feasibility and effectiveness, future studies could focus on more detailed analysis of upper-limb and walking kinematics, or the use of an assisting brace in the inhibition method.

Conflict of Interest

None.

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